



Effects of Compression, Staging, and Braid Angle on Braided Rope Seal Performance

B.M. Steinetz
Lewis Research Center, Cleveland, Ohio

Patrick H. Dunlap, Jr. and Michael L. Adams
Modern Technologies Corp., Middleburg Heights, Ohio

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EFFECTS OF COMPRESSION, STAGING, AND BRAID ANGLE ON BRAIDED ROPE SEAL PERFORMANCE

Bruce M. Steinetz
NASA Lewis Research Center
Cleveland, Ohio

and

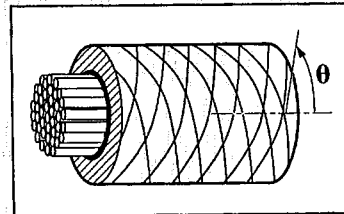
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Modern Technologies Corp.
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Background

- High temperature flexible packings have origins in several programs
 - Space Shuttle Thermal Protection System (TPS)
 - National Aerospace Plane (NASP) engine seals

Rope Seal Benefits

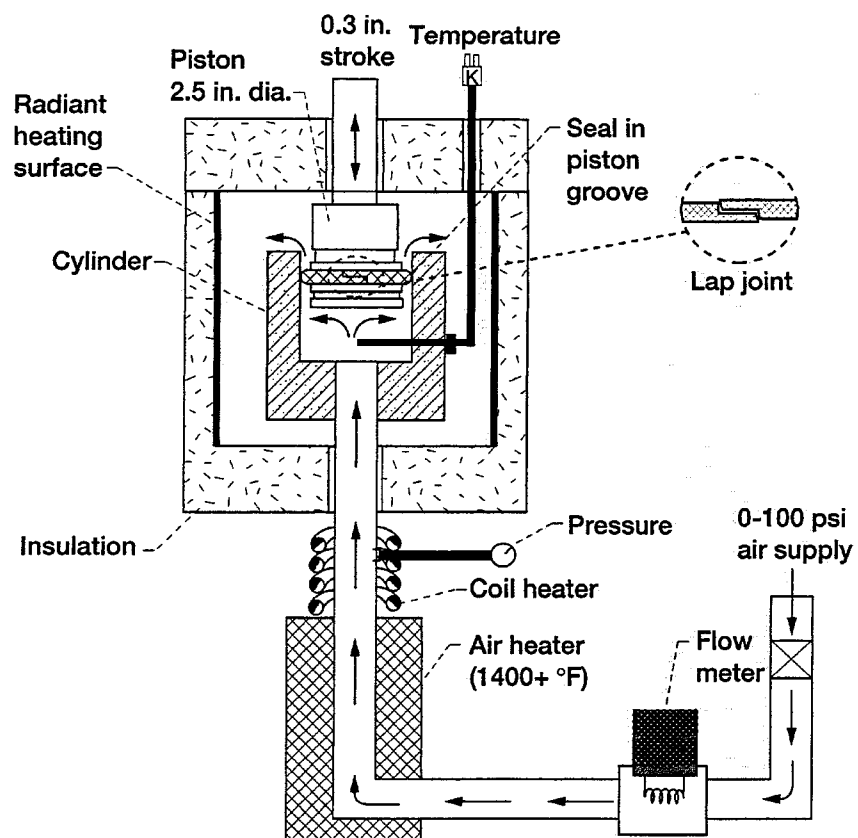
- High temperature operation (1500-2000+ °F)
→ 500-1000 °F hotter than graphite seals
- Low leakage
- Flexible: Seals & conforms to complex geometries
→ O-ring-like flexibility
- Resilient
- Allows relative thermal growth between primary/support structures
- Field joint capability
- Hybrid design resists abrasion



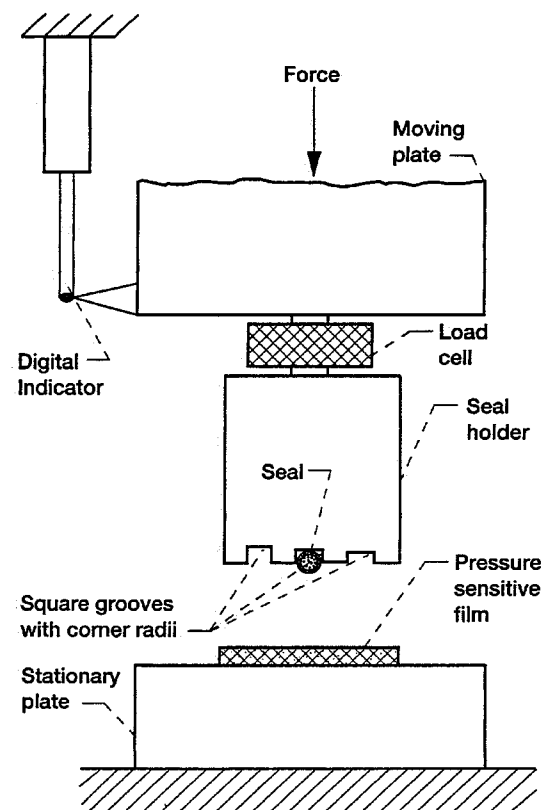
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Test Fixture Schematics

Flow Fixture

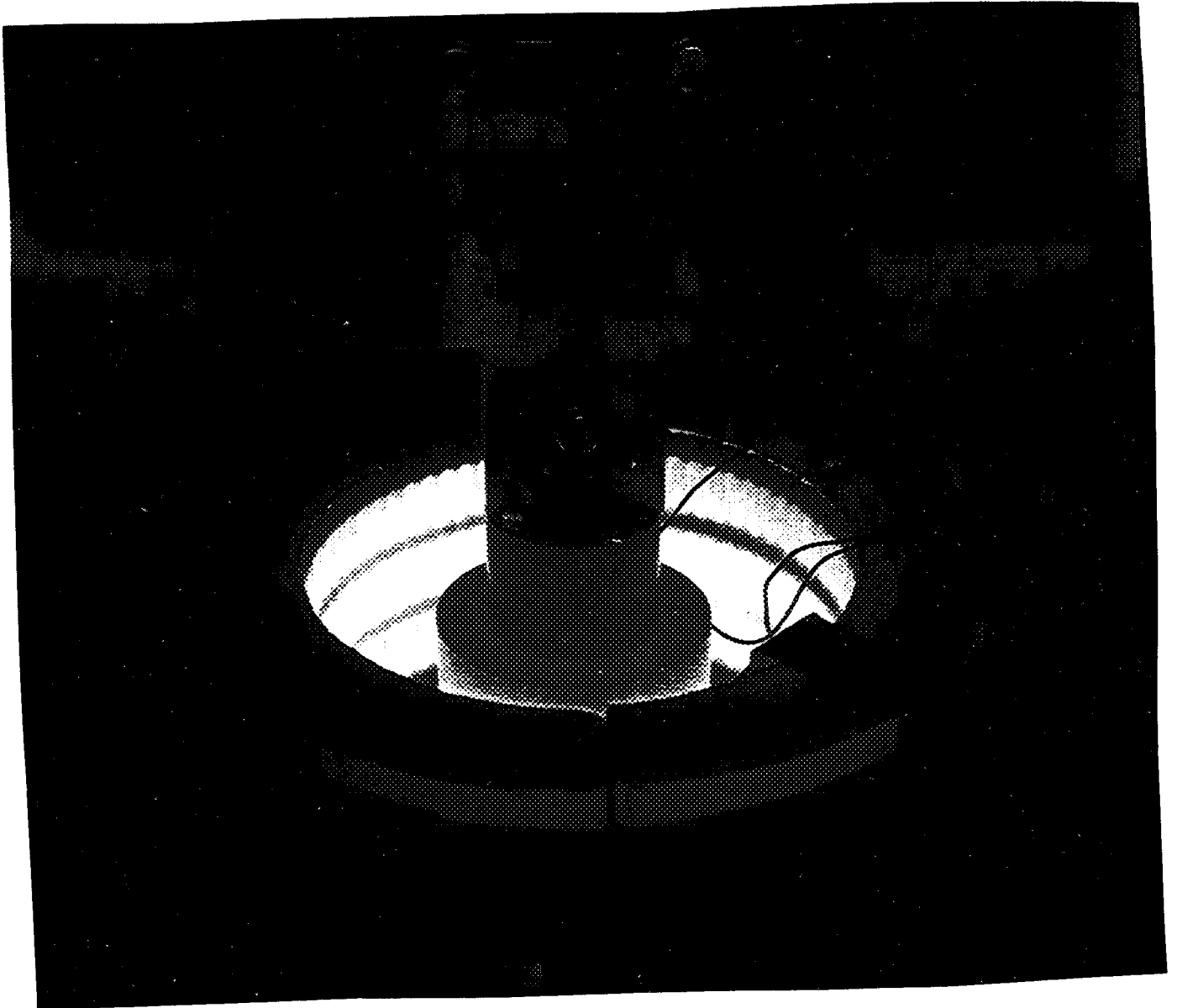


Compression Fixture



High Temperature (1500 °F)

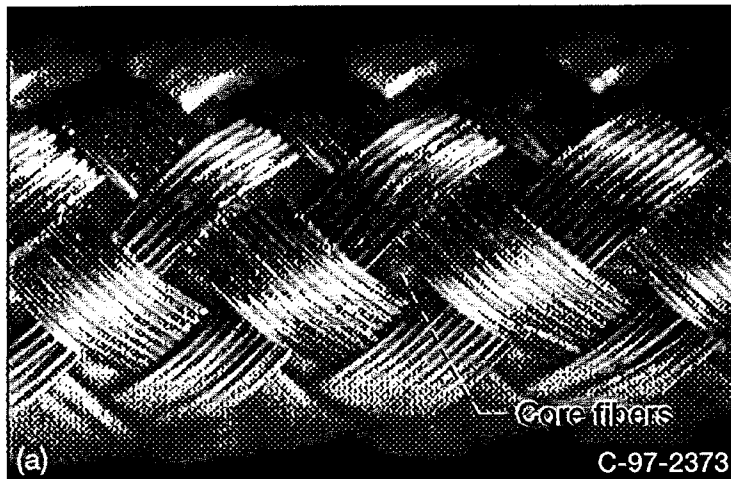
Rope Seal Test Fixture



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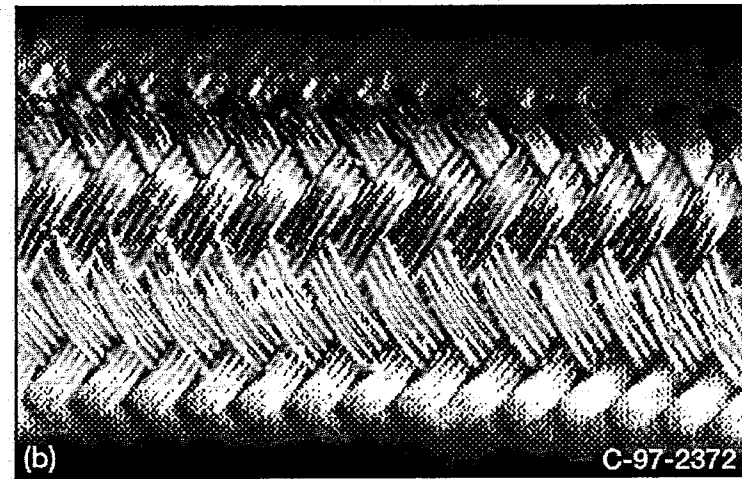
Comparison of Hybrid Seal Braid Architecture

46° Braid Angle Hybrid



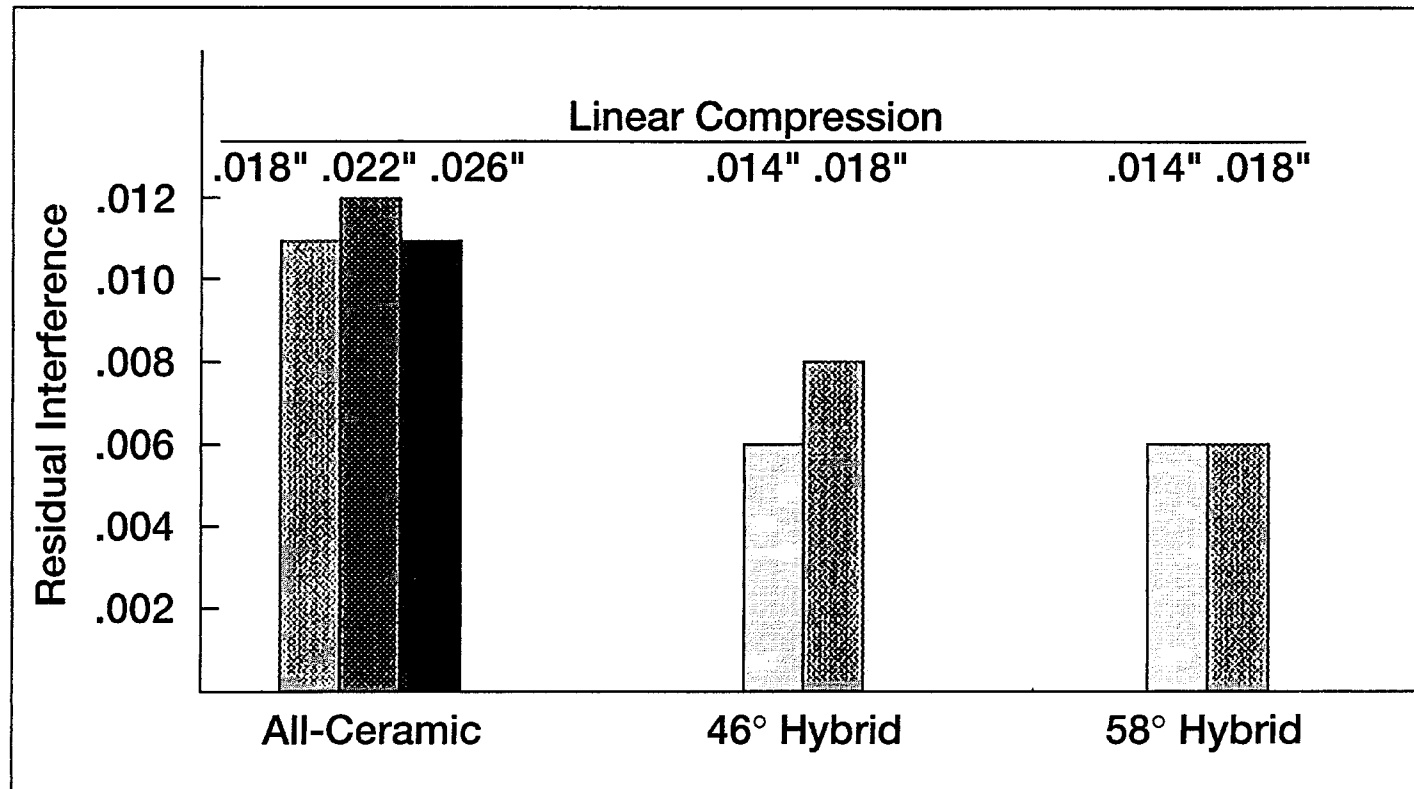
Core: Nextel 550
Sheath: Haynes 188
10 wires/bundle

58° Braid Angle Hybrid



Core: Nextel 550
Sheath: Haynes 188
4 wires/bundle

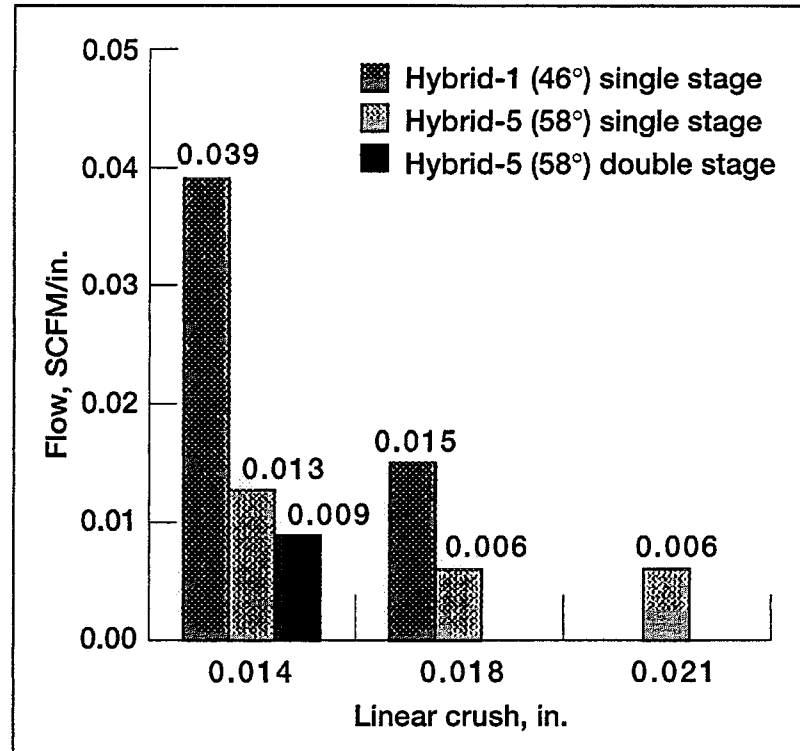
Residual Interference After Compression Cycling



All ceramic seals exhibit more residual interference

Effect of Compression, Braid, and Staging on Seal Flow ($\Delta p = 10$ psid; $T = 1300$ °F; After Scrubbing)

Hybrid Seals (1/16")

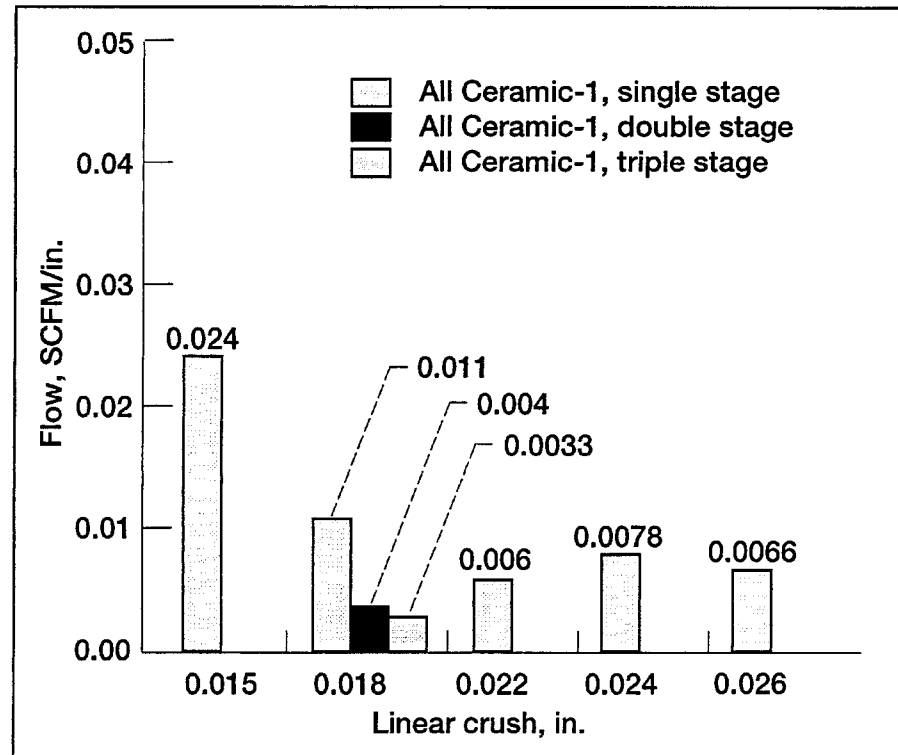


- High braid angle hybrid seal exhibited 1/2 - 1/3 the leakage of low braid angle hybrid for same linear crush, but had 6x unit pressure
- Two stage seals leaked less than single stage seals
High braid angle/high stiffness hybrid: 30+% less

Effect of Compression, Braid, and Staging on Seal Flow

($\Delta p = 10$ psid; $T = 1300$ °F; After Scrubbing)

All Ceramic Seals (1/16")

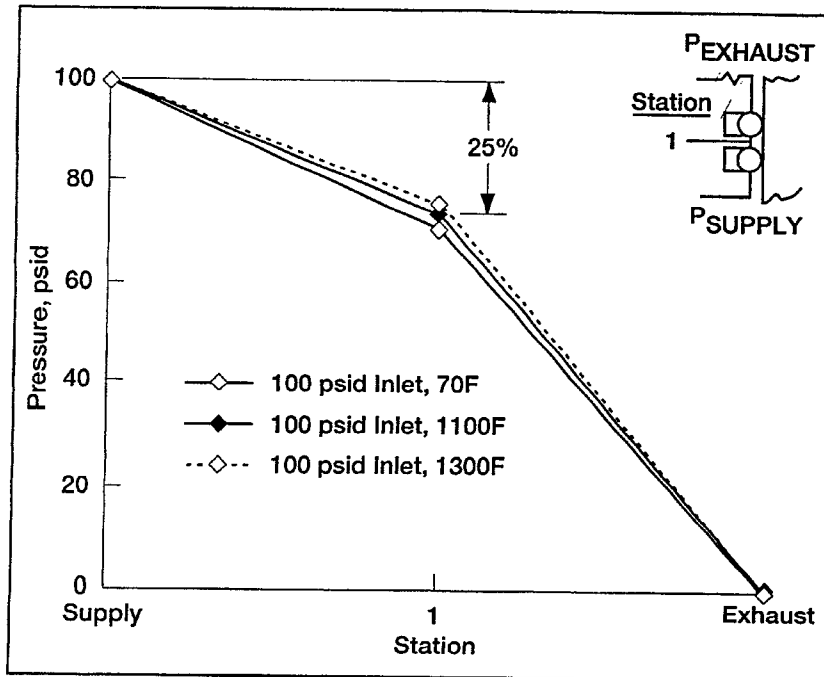


- Multiple stage seals leaked less than single stage seals
 - Two stage seals: 60% less
 - Three stage seals: 70% less

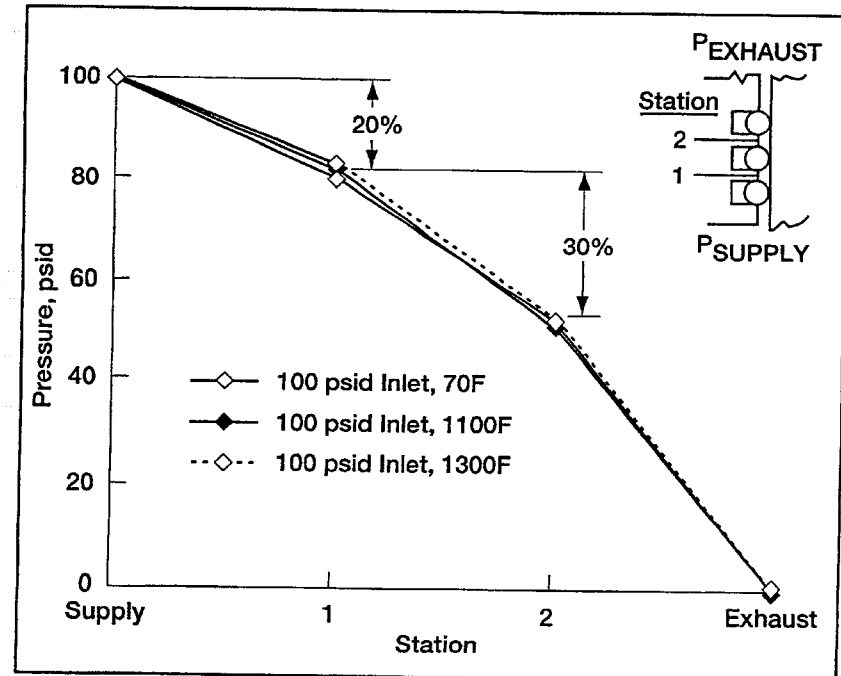
Effect of Staging on Seal Pressure Drop

Multiple Stage Seals, After Scrubbing

All Ceramic: 2 Seals
.018" Linear Crush



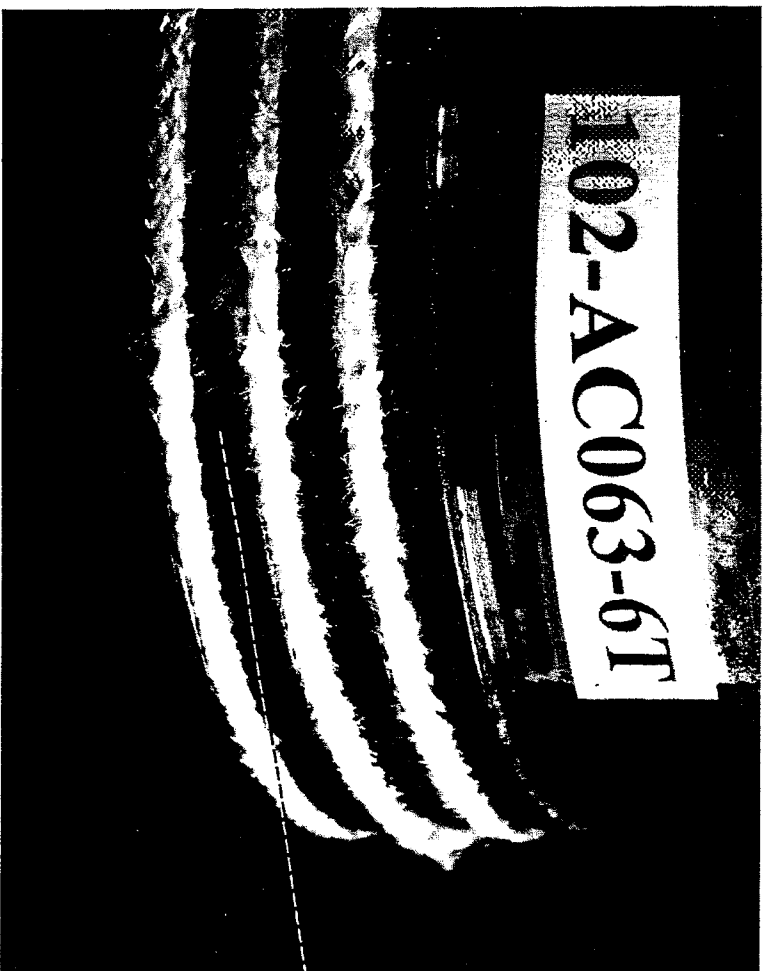
All Ceramic: 3 Seals
.018" Linear Crush



Three Stage Seal Durability

After Hot Scrubbing

10 cycles x 0.13" Stroke at 1300°F



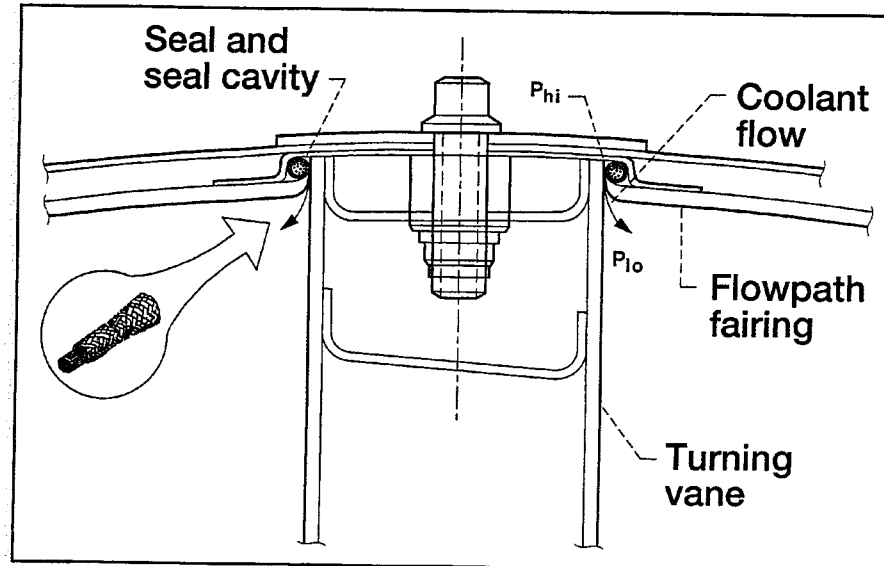
Static
Pressure
Taps
3 Places

Seals survived accelerated seal
durability cycle at temperature

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P&W Turbine Vane Seal Requirements

- Operate hot
Seal/metal temperature: 1200 °F
Gas stream temperature: last stage vane
- Exhibit low leakage – minimize cooling requirements
- Permit relative vane-to-shroud thermal growths
- Seal complex turbine airfoil geometries
- Resist abrasion in high acoustic environment
- Maintain structural integrity



Next Generation Fighter F-22

P&W F119 Engines



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Summary and Conclusions

- Increasing hybrid seal braid angle and core coverage reduced leakage 1/2 -1/3rd that of conventional hybrid for same compression but increased stiffness and unit preload
- Using multiple seals, the last stage seal always resists the largest percentage of the inlet pressure
 - + Two stage seals: 1st stage resists 25%
2nd stage resists 75%
 - + Three stage seals: 1st stage resists 20%
2nd stage resists 30%
3rd stage resists 50%
- Multiple stage seals reduced leakage considerably
 - + Hybrid seals 2 stage: 30+% reduction
 - + Ceramic seals 2 stage: 60+% reduction
3 stage: 70+% reduction

Braided Rope Seals are meeting an important need arising from increased engine cycle temperature, performance, and efficiency requirements

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